PART 2

LM3-EUTRO

James J. Pauer and Katie W. Taunt
Welso Federal Services, LLC
and
Wilson Melendez
Computer Sciences Corporation
Large Lakes Research Station
9311 Groh Road
Grosse Ile, Michigan 48138

Chapter 1. Conclusions (Executive Summary)

LM3-Eutro was developed in conjunction with several other mathematical models as part of the Lake Michigan Mass Balance Project (LMMBP). These models work together to determine contaminant concentrations in Lake Michigan fish predators under present and future conditions.

LM3-Eutro was based on the CE-QUAL-ICM model transport framework (Cerco and Cole, 1995) and used state-of-the-science eutrophication kinetics to simulate the interactions between plankton and nutrients. LM3-Eutro is a high-resolution framework containing 44,042 water column segments. The model is driven by the Princeton Ocean hydrodynamics Model (POM) (Schwab and Beletsky, 1998). A sediment model is under development. Until developed, LM3-Eutro includes user-defined fluxes to simulate sediment-water interactions. The model has 17 state variables, including a single zooplankton class, two phytoplankton classes, and several particulate and dissolved nutrient (including carbon) states.

LM3-Eutro has several advantages over historical Great Lakes models:

- A high-resolution segmentation framework (44,042 cells and 19 sigma layers), enabling a better description of areas such as nearshore and offshore zones, bays, river confluences, and the thermocline.

- Use of POM to simulate water movement is a significant improvement over historical models which traditionally used tracers, chloride, and temperature to estimate diffusive and advective flows.

- The model is carbon-based, which is an improvement over chlorophyll *a* due to high variability of this pigment in phytoplankton.

- The expansion of nutrient variables to include dissolved, labile particulate, and refractory particulate forms allows for more realistic description of phytoplankton-nutrient interactions.

- Important improvements were made to the light calculation by using a three-hour rather than 24-hour (one day) average estimate of solar radiation. The 24-hour average approach has been criticized by some scientists.

Another advantage of this modeling effort was the large supporting data set. These data were used to establish atmospheric and tributary loads, estimate initial conditions, perform model calibration and confirmation and, to a lesser extent, assist in estimating a number of kinetic coefficients. Most of the data were collected during eight sampling cruises in 1994-1995 (U.S. Environmental Protection Agency, 1997). Limited data were also collected in 1998 and 2000. The data went through rigorous quality assurance (QA) and quality control (QC) procedures (Richardson *et al*., 2004). In general, most of the emphasis was placed on the main lake as relatively little field data were collected from Green Bay. Supplemental data were gathered for loads such as shoreline erosion and internal sediment fluxes (Monteith and Sonzogni, 1976; Hall and Robertson, 1998). Most of the kinetic model coefficients were derived from the literature and historical Great Lakes models (e.g., Thomann and Di Toro, 1975; Ambrose *et al*., 1993).

The model was calibrated on the high-resolution (44,042 cells) Level 3 framework as well as the 41 segment Level 2 framework. The Level 2 calibration enabled us to visually observe known spatial and temporal trends such as the spring diatom bloom and phytoplankton concentration gradients between the epilimnion and hypolimnion. The Level 3 calibration was performed on a whole-lake basis. Model output was compared to field data for different calibration runs using simple statistical parameters such as slope and squares of the correlation coefficient. The 1994-1995 LMMBP field data were used to calibrate the model. The final calibration was chosen based on the best Level 3 calibration, but Level 2 output was visually inspected to ensure that expected phytoplankton and nutrients trends were reflected. Overall, the calibrated model fits the data well. We were especially satisfied with how well the model was able to mimic the particulate organic carbon (POC) field data because providing carbon production for use in LM2-Toxic was the most important objective of this modeling effort. The phytoplankton fit was not as good, but could be partly explained by the uncertainty in using an *in situ* fluorometer (Seabird Instrument) to estimate phytoplankton concentrations and the large natural variation in phytoplankton communities (Clesceri *et al*., 1998).

Model confirmation was performed by comparing the model to limited total phosphorus data for 1998 and 2000 and to a historical model, MICH1, which was developed and calibrated in the 1970s and modified more recently. All comparisons were done on a whole-lake basis, and LM3-Eutro fits the 1998 and 2000 data well. LM3-Eutro and MICH1 compared surprisingly well, especially given the fact that they are based on very different frameworks, kinetics, and segmentation. Compared to field data and LM3-Eutro predicted, MICH1 underpredicted both total phosphorus concentrations. This was probably due to the fact that MICH1 does not have any phosphorus internal sediment recycle. Lower phosphorus values also caused MICH1 to underpredict chlorophyll *a* concentrations in the lake.

Several model forecast scenarios were performed, and long-term total phosphorus, POC, and phytoplankton predictions were observed. One scenario utilized alternating 1994 and 1995 tributary and atmospheric phosphorus loads for 30 years. The autochthonous solid (primary production carbon) output from this model was used in the contaminant fate and transport polychlorinated biphenyl (PCB) model. The model predicted a steady-state total phosphorus concentration of 4.3 µg/L, a steady-state POC concentration of 0.2 mg/L, and an epilimnetic spring chlorophyll *a* peak of 2.36 µg/L. Steady-state was reached within 28 years. Several load reduction scenarios were performed, and total phosphorus, POC, and chlorophyll *a* concentrations were predicted. The Great Lakes Water Quality Agreement (GLWQA) target total phosphorus load of 5,600 MT was revisited and the impact of increasing the load to this level was predicted for total phosphorus and chlorophyll *a* concentrations in the lake (International Joint Commission, 1978). Under the GLWQA loading levels, total phosphorus concentrations were predicted to reach 7.5 µg/L, and spring epilimnetic chlorophyll *a* peaked at 4.0 µg/L. The model was used to estimate the total phosphorus loading required to reach the International Joint Commission's (IJC) total phosphorus concentration guideline of 7 µg/L (Great Lakes Research Advisory Board, 1978). The model predicted that an annual load of 5,020 maximum total (or a Total Maximum Daily Load (TMDL) of 14 maximum total/day) would result in the 7 μg/L steady-state total phosphorus concentration and a spring maximum epilimnetic chlorophyll *a* concentration of 3.7 μg/L.

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